

VALUE TRANSMISSION IN DISCRIMINATION
LEARNING INVOLVING STIMULUS CHAINS

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Rats learned a series of reversals of a positional discrimination in which responses to one lever led to delayed food and responses to a second lever led to no food. Interpolated within the delays leading to the different outcomes were two-link stimulus chains. The pairing of each stimulus element with the delayed outcome of food or no food varied across reversals. Either stimulus element could have the same correlation with outcome as occurred on the preceding reversal or the opposite correlation as on the preceding reversal. New reversals were acquired more quickly when both stimulus elements had the same status as during the preceding reversal, and were acquired most slowly when both stimulus elements had the opposite status as that of the preceding reversal. The rate of learning was intermediate when only one of the stimulus elements had the same status as that during the preceding reversal. All of the data are compatible with an interpretation in terms of backward chaining of stimulus value.

Key words: chain schedules, conditioned reinforcement, delay of reinforcement, discrimination learning, lever press, rats

Since the classic study of Grice (1948), it has been an accepted fact that simultaneous discrimination learning is greatly impaired when the consequences of choice are delayed relative to when the response consequences are immediate. Moreover, stimuli inserted into the delay interval may greatly counteract the retardation effect caused by the delay. Because behavioral control by delayed consequences has implications for many different areas of psychological research (e.g., self-control), understanding the mechanism by which the stimuli inserted within a delay-of-reinforcement interval facilitate learning is fundamentally important.

The classic interpretation of the effects of stimuli inserted in delay-of-reinforcement intervals, again dating back to Grice (1948) and Spence (1947), has been in terms of conditioned reinforcement. Stimuli presented just prior to the delivery of reinforcement are assumed to gain value due to their pairing with the reinforcer, and then, because their presentation is contingent on the choice response, transmit that conditioned value differentially to the choice stimuli, thus producing the discrimination. Substantial

data support this interpretation (e.g., Cronin, 1980).

Nevertheless, other mechanisms by which stimuli may facilitate learning about delayed consequences have also been proposed, including *bridging* and *marking* (for a discussion of these alternative mechanisms, see Williams, 1994). Bridging is said to occur when a stimulus interposed between a response and a delayed outcome facilitates the association between the associative elements without itself being necessarily associated with either. The process by which this occurs is not well specified, but Rescorla (1982) has likened it to a gestalt perceptual process by which the intervening event creates a catalysis of the associative connection. Marking is said to occur when a response-contingent stimulus highlights that response and causes it to be more memorable at the time the delayed consequence is presented, thus allowing a greater association between the response and outcome.

Marking and bridging differ from conditioned reinforcement as explanatory concepts in terms of the role played by the value of the stimuli inserted in the delay of reinforcement. Whereas both bridging and marking imply that such stimuli may facilitate learning even though they have no value in their own right (Lieberman, McIntosh, & Thomas, 1979; Rescorla, 1982), the concept of conditioned reinforcement implies that

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the transfer of value between stimuli is the critical process by which the facilitation of learning occurs.

Prior work investigating how discrimination learning is affected by delayed reinforcement has focused primarily upon procedures in which a single stimulus has been presented within the delay-of-reinforcement intervals. In contrast, studies of chain schedules of reinforcement of operant behavior have often used chains with multiple links, such that more than one stimulus may intervene between the responses in the initial link of the chain and the delayed outcome at the end of the chain. This distinction is noteworthy because chains with multiple stimulus links have produced results that appear to challenge the concept of the backward transmission of value as the underlying mechanism by which delayed reinforcement controls behavior. In general, the greater the number of intervening stimulus links, while holding the total time to food constant, the more poorly behavior in the initial link is maintained (Duncan & Fantino, 1972; Leung & Winton, 1988; but see Vaughan, 1985, for an account of this effect in terms of backward chaining). Moreover, chains with more than two links maintain little if any behavior in the initial link of the chain (for a review, see Gollub, 1977).

Discrimination procedures like that used by Grice (1948) are very different from the procedures used to study the maintenance of free-operant behavior in chain schedules of reinforcement. There is little information regarding how discrimination learning is affected by the delay interval between choice behavior and outcome when a chain of stimuli is presented during the delay-of-reinforcement interval. The present study is an attempt to address this issue.

The procedure used in the present study was a simultaneous discrimination between two levers. Choice of one lever always led to food at the end of one stimulus sequence, whereas the choice of the other lever led to no food at the end of a different stimulus sequence. After initial learning of this discrimination, the reward value of the two choice alternatives was reversed. At issue was the role of the stimuli intervening between the choice and its outcome in determining how rapidly the reversal in the reinforcement contingencies was learned. More specifically,

Choice Phase	Middle Link	Terminal Link	Outcome
Reversal N			
Right	Light	Noise	Food
Left	Flash	Click	No Food

Reversal N+1			
M=Same, T=Same			
Right	Flash	Click	No Food
Left	Light	Noise	Food
M=Same, T= Reversed			
Right	Flash	Noise	No Food
Left	Light	Click	Food
M= Different, T= Same			
Right	Light	Click	No Food
Left	Flash	Noise	Food
M = Different, T = Different			
Right	Light	Noise	No Food
Left	Flash	Click	Food

Fig. 1. Outline of the different types of stimulus contingencies presented on different reversal problems. Note that the designation of same or reversed refers to the relation between the stimulus and trial outcome relative to the prior reversal.

how was the rate of learning determined by changes in the value of the intervening stimuli?

The basic idea of the experiment can be illustrated by reference to Figure 1. The top portion of the figure, labeled Reversal N, gives one example of the discrimination contingencies: Choice of the right lever led to food at the end of the stimulus chain; choice of the left lever led to a different stimulus chain ending in no food. After this problem was learned, the lever that led to food was reversed but with different changes in the intervening stimuli depending upon the experimental condition. The most basic comparison was between the conditions labeled middle (M) = same (S) terminal (T) = S versus M = different (D) T = D. In the S condition the stimuli that intervened between the choice response and outcome were reversed in their correlation with the response, but remained the same in terms of their correlation with the choice outcome. Thus, the light that had led to food in Reversal N continued to lead to food in Reversal N + 1, despite the fact that the lever leading to food

had been reversed. In the condition designated $M = D \ T = D$, the correlations between the intervening stimuli and reward were reversed, while the correlation between the chosen lever and following stimuli continued as they had during Reversal N.

To the extent that the stimuli within the delay interval facilitate learning because their own conditioned value mediates the delay interval, consistent stimulus-reinforcer correlations across successive reversals of the discrimination should facilitate learning relative to when the stimuli themselves have inconsistent correlations with the reward outcome. In comparison, if the stimulus chain facilitates learning by serving as a bridge between the choice and its outcome, changing the relationship among the elements of the bridge, by reversing the correlation between the choice response and intervening stimuli, should disrupt learning. Similarly, if the facilitation of learning were due to the marking of the correct choice by the onset of the intervening stimuli independent of their value, changes in the correlations of the intervening stimuli with trial outcome should be irrelevant.

The middle two conditions shown in Figure 1, designated $M = S \ T = D$ and $M = D \ T = S$, allow a more intricate assessment of the dynamics of changes in stimulus value. If backward transmission of stimulus value is critical to learning each new reversal of the discrimination, keeping the correlation consistent between the middle-link stimulus and trial outcome should facilitate learning, quite independent of the status of the terminal-link stimulus. On the other hand, when the middle-link stimulus is reversed in value, the status of the terminal-link stimulus should become important, because the value of the terminal-link stimulus is critical to retraining the value of the middle-link stimulus. In comparison, if some kind of bridging function is served by the intervening stimuli, there is no reason to suppose that there should be a differential effect of changing the correlations between trial outcome and the middle-versus terminal-link stimuli.

METHOD

Subjects

Eight Sprague-Dawley albino rats, approximately 6 months of age at the start of the

experiment, served as subjects. All had prior experimental experience in a successive discrimination problem in a different experimental apparatus. Food deprivation was maintained by allowing 90-min access to laboratory chow approximately 5 min after the end of the experimental sessions. Water was continuously available in the home cages at all times. Subjects were housed in individual cages with a 14:10 hr light/dark cycle; experimental sessions occurred during the light portion of the cycle.

Apparatus

A custom-built conditioning chamber, 24 cm wide by 20 cm high by 26 cm long, was contained within a larger sound-insulating shell, which was equipped with an electric fan for ventilation. The interior chamber was constructed of Plexiglas except for a sheet-metal rear wall and wire-grid floor. The front panel of the chamber was painted black; the remaining walls and ceiling were clear Plexiglas. Mounted on the front panel 11.5 cm above the floor were two nonretractable stainless steel levers, 3 cm in width and protruding 1.8 cm into the chamber. Each lever required a force of at least 0.2 N for operation, with the only feedback for a response being the action of a microswitch connected to the other end of the lever. Directly below each lever and 2 cm above the grid floor was a pellet chute connected to an electromechanical 28-V pellet dispenser (Gerbrands Model G5100), which provided standard 45-mg Noyes chow pellets (improved Formula A). Throughout this experiment, pellets were delivered only to the pellet chute under the right lever.

Mounted 4 cm above the outer edge of each lever was a 28-V miniature light (Sylvania 28 ESB) encased within a recessed bulb holder. A third miniature light was located in the middle of the chamber, midway between the two lights located near the levers. This center light flashed with a frequency of 4.5 Hz when presented as a stimulus. Located on the outside of the left side wall was a clicker module (Coulbourn Model E12-05), which presented a 5-Hz auditory clicking stimulus, approximately 80 dB in intensity. Mounted on the rear portion of the ceiling was a 4-Ω speaker through which 80 to 85 dB white noise could be delivered. Mounted on the outside of the right wall of the interior cham-

ber was an unshielded 28-V lamp (bulb 1820) that could illuminate the entire experimental chamber with continuous white light.

Procedure

Because all subjects had been trained to press a lever in a different apparatus, they were begun immediately on the initial discrimination. At the onset of a trial, the two panel lights above the right and left levers were illuminated simultaneously. Responses to either lever changed the stimuli to those associated with the middle link of the schedule according to a single variable-interval (VI) 20-s reinforcement schedule. When the prevailing VI interval had elapsed, the location of the next response terminated the front panel lights and determined which stimulus chain was begun. For the initial discrimination all subjects received the same sequence of stimuli. A response to the right lever illuminated the houselight located on the outside of the chamber; a response to the left lever began the flashing of the light located in the middle of the front panel, between the two levers. Additional responses during these stimuli had no scheduled effect. The middle-link stimuli continued according to a variable-time (VT) 15-s schedule. When the prevailing interval elapsed, the middle-link stimulus in effect changed to the terminal-link stimulus appropriate to that chain. In the initial discrimination problem, the terminal-link stimulus in the chain begun by the choice of the right lever was white noise, and the terminal-link stimulus in the chain started by the left lever was a clicker. As in the middle link, responses during the terminal link had no scheduled effect. The terminal-link stimuli terminated automatically according to a fixed-time (FT) 20-s schedule. If the positive discriminative stimulus (S+) chain was in effect, a food pellet was delivered, along with the illumination of the panel lights indicating the start of the next trial. If the negative discriminative stimulus (S-) chain was in effect, only the onset of the panel lights occurred. Training on the initial discrimination continued for five sessions. Individual sessions continued until 50 food pellets had been obtained or until 50 min had elapsed.

After acquisition of the initial discrimination, the choice response that led to food (S+) was reversed, such that choices of the

left lever now led to food. The stimuli constituting the middle and terminal links were also changed, but differentially for different subjects. The four possible types of change are shown in Figure 1. In Condition M = S T = S, the middle-link and terminal-link stimuli that had led to food continued to lead to food, but now after the choice of the left lever. In Condition M = reversed (R) T = R, the middle- and terminal-stimuli that had led to food now led to no food, but these stimuli continued to be presented after the same choice response as during the previous discrimination problem. In the remaining two conditions, the middle-link stimulus that led to food was reversed, while the terminal-link stimulus was the same (M = R T = S), or the middle-link stimulus that led to food remained the same while the terminal-link stimulus was reversed (M = S T = R). Two subjects were trained on each of these four types of stimulus contingencies. Training continued on each discrimination problem for 10 experimental sessions.

After training on the initial reversal problem had been completed, the choice response that led to food was again reversed, and each subject received a new arrangement of middle- and terminal-link stimuli. A total of four reversals were presented, such that each subject received one reversal for each of the four types of reversals shown in Figure 1. The order of the different conditions was counterbalanced across subjects. The designation of whether a stimulus was reversed or remained the same relative to the preceding reversal was always in reference to the correlation of the stimulus with the trial outcome of food or no food.

RESULTS

The rate of discrimination learning for the various stimulus arrangements was measured by calculating the percentage of responding that occurred each session during the choice phase to the lever that produced the stimulus chain that led to food at the end of the chain (the S+ lever). Because each subject received each type of stimulus arrangement for one reversal, the data for a particular type of stimulus arrangement was averaged over individual subjects, and the mean results for the four different conditions were compared with a

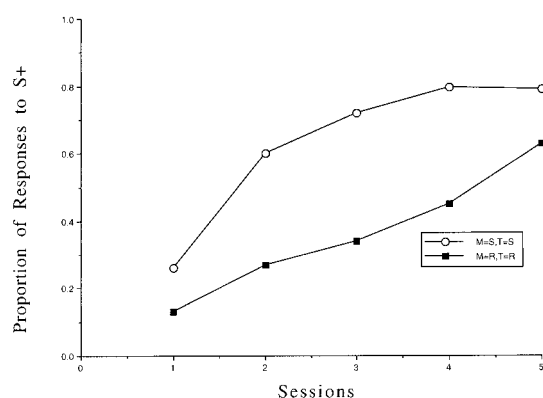


Fig. 2. Acquisition functions for reversals in which both stimulus links of the chain were reversed in value versus those in which both stimulus links of the chain were the same as on the preceding reversal.

two-way within-subject analysis of variance (ANOVA) (Condition \times Sessions). Only the first five sessions of training on each reversal were analyzed because all conditions converged toward a very high level of discrimination accuracy by the end of the 10 sessions of training. The additional sessions were presented in order to ensure that all subjects were performing at asymptotic levels on the preceding problem before the reinforcement contingencies were reversed. The results of the ANOVA were that the effect of experimental condition was significant, $F(3, 21) = 4.62$, $p < .05$; also significant was the effect of sessions of training, $F(4, 28) = 94.7$, $p < .01$; the interaction term was not significant, $F(12, 84) = 1.60$. In all of the remaining analyses the sessions variable was always significant, and will be ignored.

Figure 2 shows the rate of acquisition for reversal problems in which both the middle- and terminal-link stimuli were reversed from their prior values in comparison to the reversal problems in which the reward value for both types of stimuli remained the same as that on the preceding reversal. Substantially faster learning occurred for reversals in which the value of the stimuli was the same as that of the preceding reversal. This difference was evident throughout the first five sessions, and was statistically significant, $F(1, 4) = 9.30$. The interaction between stimulus condition and sessions of training was not significant, $F(4, 28) = 2.07$, $p > .10$.

The results shown in Figure 2 were due to

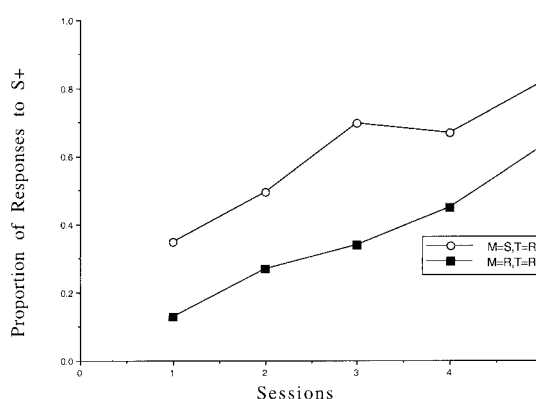
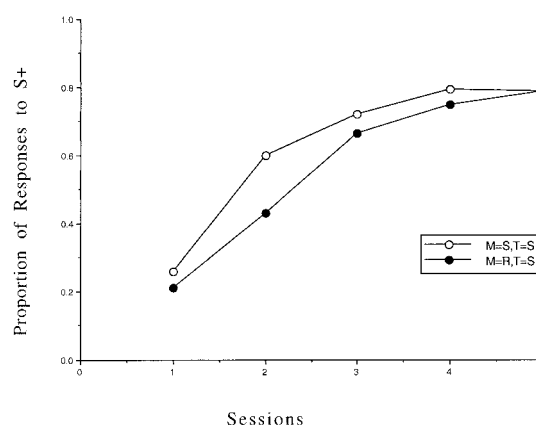


Fig. 3. Acquisition functions for reversals in which the values of the middle-link stimuli were the same or reversed from the values of the preceding reversal. The different panels show how this comparison was affected by the reversal status of the terminal-link stimuli.

the sum of the effects of the middle- and terminal-link stimuli either both being reversed or both kept the same with respect to their correlation with the trial outcome on the preceding reversal. The top portion of Figure 3 isolates the effects of the value of the middle-link stimulus while keeping the value of the terminal-link stimulus the same as the preceding problem. There was a slightly faster rate of learning when the middle-link stimulus had the same value as that of the preceding reversal, but a two-way ANOVA revealed that the effect of stimulus condition was not significant, $F(1, 7) < 1$. The interaction between stimulus condition and sessions of training was also not significant, $F(4, 28) = 1.41$, $p > .20$. The bottom portion of Figure 3 isolates the effect of the value of the middle-link stimulus when the value of the ter-

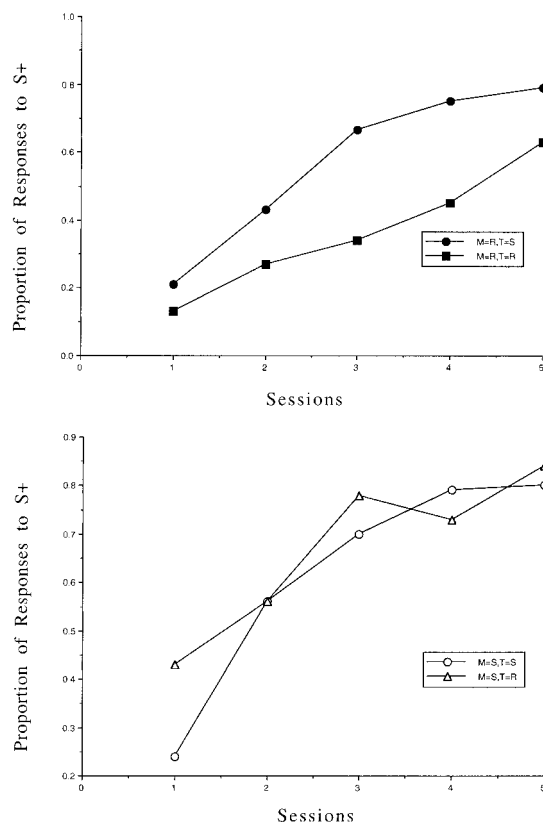


Fig. 4. Acquisition functions for reversals in which the values of the terminal-link stimuli were the same or reversed from the values of the preceding reversal. The different panels show how the comparison was affected by the reversal status of the middle-link stimuli.

minal-link stimulus was reversed from that of the preceding reversal. When the middle-link stimulus retained its value from the preceding reversal, the rate of learning was substantially higher than when the middle-link stimulus had its value reversed. A two-way ANOVA showed the effect of stimulus condition to be significant, $F(1, 7) = 15.9$, $p < .01$, but the interaction between stimulus condition and sessions of training was not significant, $F < 1$.

Figure 4 shows how rate of learning was affected by whether the terminal-link stimulus had the same or reversed value from that of the preceding reversal. The top portion shows this comparison when the value of the middle-link stimulus was reversed from that of the preceding reversal. Retaining the value of the terminal-link stimulus from the previous reversal substantially increased the rate of learning. Here the effect of stimulus condi-

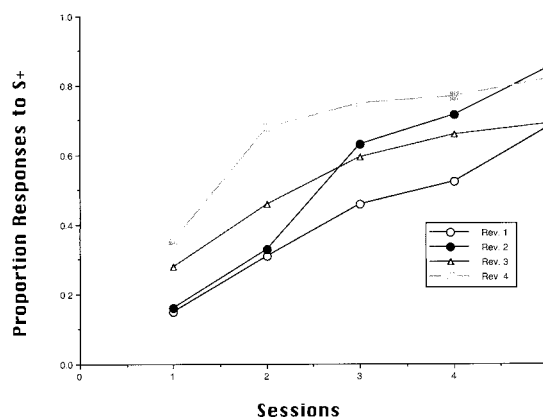


Fig. 5. Acquisition functions averaged over all four stimulus conditions. Separate functions are plotted for Reversals 1 through 4.

tion was significant, $F(1, 7) = 6.98$, $p < .05$, but the interaction between sessions and condition was not significant, $F(4, 28) = 1.64$, $p > .10$. The bottom portion of Figure 4 shows the effect of whether the value of the terminal-link stimulus was the same or reversed from that of the preceding reversal when the middle-link stimulus retained its value from the preceding reversal. Here the effect of stimulus value was not significant, $F < 1$, but the interaction between stimulus value and sessions was statistically significant, $F(4, 28) = 2.75$, $p < .05$.

Each individual subject received all four experimental conditions shown in Figure 1, but an examination of their effects for individual subjects is confounded by the fact that significant changes in the acquisition functions occurred across the four separate reversals independent of the experimental condition. Figure 5 shows these changes across successive reversals. Note that the data for each reversal number includes 2 subjects from each experimental condition, but that the subjects corresponding to each condition changed randomly over reversals because of the complete counterbalancing of the experimental design. The major finding shown in Figure 5 is that the rate of learning increased across successive reversals, primarily during the first three sessions of each reversal. Because of these changes, a comparison for individual subjects of the effects of the experimental conditions is inappropriate.

An indication of the typical nature of the

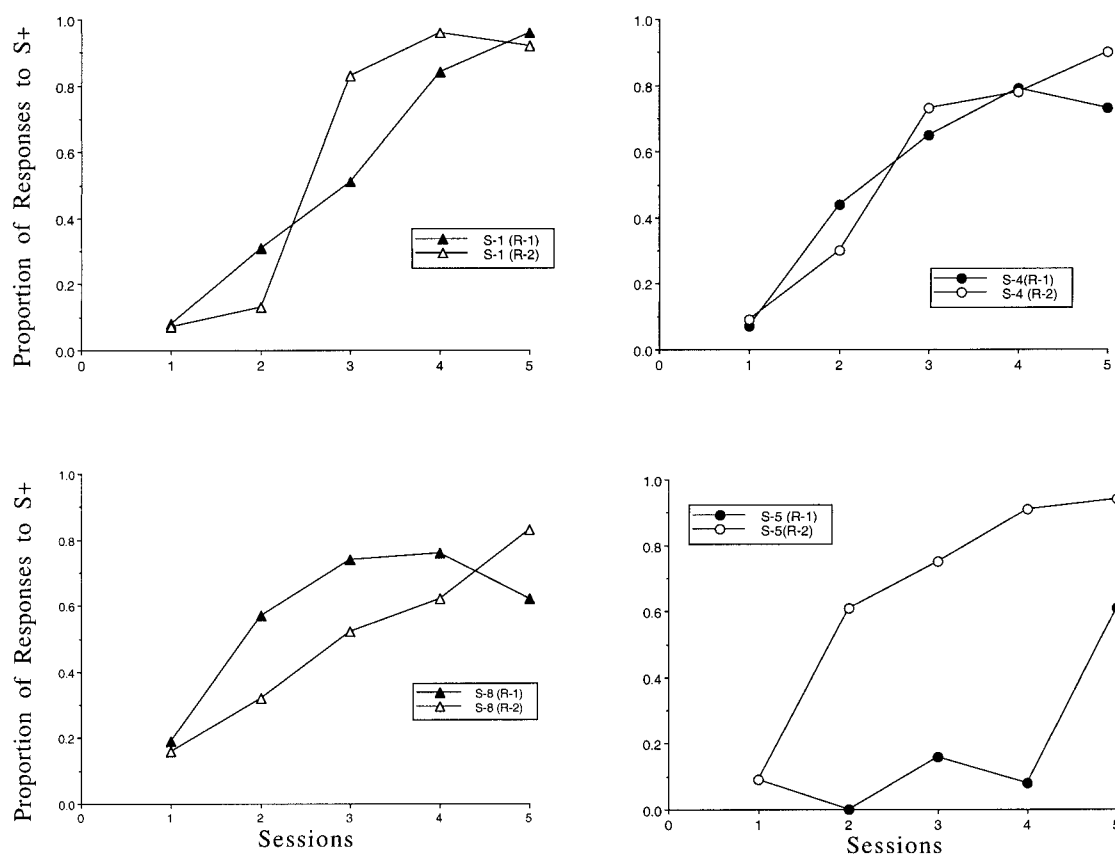


Fig. 6. Acquisition functions for individual subjects for Reversals 1 and 2. Subjects shown in left panels were trained on middle = same terminal = same for the first reversal. S-1 was trained on middle = reversed terminal = same for the second reversal, and S-8 was trained on middle = same terminal = reversed for the second reversal. Subjects shown in right panels were trained on middle = reversed terminal = reversed for the first reversal. S-4 was trained on middle = reversed terminal = same for the second reversal, and S-5 was trained on middle = same terminal = same for the second reversal.

acquisition functions is seen in Figure 6. Shown on the left side are the two subjects that were trained during the first reversal on $M = S \ T = S$. Shown on the right side are the 2 subjects that were trained during the first reversal on $M = R \ T = R$. The acquisition functions for the second reversal are also shown for each subject, but the conditions of the second reversal varied across subjects, as described in the figure caption.

If the mean results shown in Figures 2 through 4 were representative of the individual subjects regardless of the order of the conditions, Subjects S-1 and S-8 should have exhibited faster acquisition during the first reversal than during the second reversal, because the $M = S \ T = S$ condition produced the fastest learning overall. This was mostly

true for S-8, except for the downturn in correct responding on Session 5. However, there was no consistent difference in acquisition rate for S-1, as its two acquisition functions crossed over. For S-4 and S-5, which received $M = R \ T = R$ during the first reversal, slower acquisition should have occurred on the first reversal rather than on the second reversal. There was no difference for S-4, but a very large difference occurred for S-5. Note that the condition received by S-5 during the second reversal was $M = S \ T = S$, which should have produced the fastest rate of learning.

DISCUSSION

The critical issue addressed by the present study was whether the rate of learning of a

simple simultaneous positional discrimination, in which signaled delay intervals intervened between the choice responses and their outcomes, would be affected by variations in the value of the stimuli intervening in the delay intervals. Manipulations of stimulus value should be irrelevant if the constructs of either marking or bridging are the proper theoretical interpretation, but such manipulations should be critically important if the stimuli during the delay-of-reinforcement intervals facilitate learning due to their role as conditioned reinforcers.

In the present study, a chain of two stimuli intervened between choice and outcome. When the levers assigned as S+ and S- had their value reversed, the most rapid learning of the reversal of the new lever-food contingency occurred when both elements of the intervening stimulus chain retained their value from the previous discrimination. With reference to the conditions shown in Figure 1, the fastest learning occurred for the condition designated as $M = S\ T = S$. Thus, the concept of conditioned reinforcement appears to be necessary to explain the present results, because neither of its theoretical competitors regard the value of the intervening stimuli to be critical to their role in facilitating learning.

Two-way comparisons of the four conditions shown in Figure 1 provide some insight into the dynamics of how changes in stimulus value affected the rate of discrimination learning. Whether or not the middle-link stimuli retained their value from the preceding reversal had little effect on the rate of learning when the terminal-link stimuli retained their prior values, but had a major impact when the values of the terminal-link stimuli were reversed. Similarly, retaining or reversing the values of the terminal-link stimuli had different effects depending on the status of the middle-link stimuli. When the middle-link stimuli had their values retained from the preceding reversal, reversals in the status of the terminal-link stimuli had relatively little effect, but when the value of the middle-link stimulus was itself reversed, the status of the terminal-link stimulus had a large effect on the rate of learning.

This complex pattern of results can be explained by the assumption that the critical determinant of the rate of discrimination learn-

ing was the value of the middle-link stimulus, and the additional assumption that the value of the terminal-link stimulus modulated the value of the middle-link stimulus. Thus, when both the middle-link and terminal-link stimuli retained their value from the preceding reversal, acquisition of a new reversal required only that the subject learn the new association between the chosen lever and middle-link stimulus. Because the middle-link stimulus retained its status as a conditioned reinforcer, such learning occurred rapidly. In contrast, when both the middle and terminal links had their values reversed, the subject first had to relearn the value of the terminal-link stimulus, then relearn the value of the middle-link stimulus, while the relation between the chosen lever and middle-link stimulus remained intact. The time required for relearning the value of both types of stimuli then determined the rate of learning of the discrimination.

The results shown in Figures 3 and 4 also can be accounted for in this explanatory framework. The reason that reversals in the value of the terminal-link stimuli had little effect when the middle-link stimuli retained their value is that the critical contingency was the value of the middle-link stimuli immediately contingent on the choice response. Given that these values were unchanged from the preceding reversal, learning to reverse the choice response could occur quickly. Presumably, at the start of a new reversal under this condition ($M = S\ T = R$), the previously negative middle-link stimulus received some increment in positive value because of residual conditioned reinforcement possessed by the terminal-link stimulus previously paired with food. But at the same time, this terminal-link stimulus was being extinguished in value because it now was no longer followed by food. Thus, any conditioning of positive value to the negative middle-link stimulus should be transitory and should interfere relatively little with the acquisition of the new reversal.

The findings shown in Figure 4 require a related but different account. A differential effect of retaining versus reversing the value of the middle-link stimulus occurred only when the values of the terminal-link stimuli also were reversed. When the terminal-link value retained its status from the preceding reversal, its conditioned reinforcement prop-

erties could quickly retrain the value of the middle-link stimulus that had served as an S- on the preceding reversal. But when the terminal-link value was itself reversed, any retraining of the value of the middle-link stimulus could occur only after the retraining of the value of the terminal-link stimulus that previously had appeared on S- trials.

The foregoing analysis is speculative, in part because no direct measure of the changes in value during the middle and terminal links is available. This is the result of the decision not to use response requirements during these stimuli in order to avoid variation in the obtained times spent in each link of the chain. Despite this limitation, the results make a strong case that the effect of stimuli intervening between choice responses and their outcomes exert their effect on the rate of learning by providing an avenue of transmitting the value of the outcomes in a backwards direction to the values of the choice alternatives. Taken together with previous results (Williams, 1994, 1997; Williams, Ploog, & Bell, 1995), the present study supports the thesis that understanding the conditioned reinforcement properties of the intervening stimuli is critical to predicting when intervening stimuli will or will not facilitate learning.

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